

## Introducing Remark

7<sup>th</sup> ready day of QM intense discussion of philosophical issues (the analysis of concepts, principles and ultimate presuppositions) of the theory. This culminated in 1935 with EPR debate between Einstein and Bohr (and Copenhagen camp) which was officially declared the winner. Bohr reigned supreme until the 1960s, except for the efforts of Bohm to construct R.V. models of QM. This was partly due to the influence of von Neumann's no-go theorem proved in the oft-cited but little read *Mathematical Grundlagen der Quantenmechanik* (1932).

Main technical advance was Gleason's theorem (1957) on probability measures that could be defined on the projection lattice of a Hilbert space. This theorem proved to be key to the work of Bell and Speiser (1967). A parallel development was the discovery of a non-locality property of R.V. theories in 1964. This was the Bell inequalities which led to many experimental tests culminating in the work of Aspect, Dalibard and Roger about 1980 onwards.

Notice different reactions here as between Physicists & Philosophers.

Aspect's result expected by physicists - regarded by many philosophers as revolutionary removal of instrumentalist (statistical) interpretation of QM and used by most physicists. Philosophers want to understand



N.B.  $2P_{\text{system}}$  is a N.D. wave function, but it is the exact fun of the relative norm of the 2-body spin wave function related to an appropriate phase of reference for a slowly moving 2-body system

In order to proceed we distinguish 3 versions of the individual particle interpretation of DM wheel call A, B & C.

Thus given

3 means an observer not in an eigenstate

- A) Sharp unknown value
- B) unsharp or 'fuzzy' value
- C) Undefined or meaningless value.

cp DM is not mysterious mysterious with new concepts like potentiality or latency, and mysterious in recognizing limitations on the applicability of old concepts.

3 means a latent measurement does

- A) Do-existing value revealed
- B) Potential & latent value actualized
- C) Undefined value becomes defined.

How is this change brought about?

- 1) Interaction with a physical instrument
- 2) Action of human consciousness

## The EPR Argument (1935)

This is an argument for the incompleteness of QM.

EPR takes as necessary condition for

Completeness: Every element of reality has a counterpart in the theory, associated with it.

They take as sufficient condition for an element of reality: If without disturbing a system we can predict with certainty the value of an observable already, before the prediction, then exists an element of reality corresponding to that observable.

The EPR argument is based operationally on wave B and shows that this wave is incomplete in the sense that even in non-disturbing observations do have sharp values (not referred to in position B).

So the argument wishes now turn to position A.

But the argument wishes a locality assumption

Locality: Unsharp  $\rightarrow$  sharp at a distance

(Disturbing Bell and Einstein zone of interaction)

Bohr's response to EPR was to query whether we should not well insist upon C and use

Locality<sub>2</sub>: undefined  $\rightarrow$  defined  
'at-a-distance' forbidden

But this does purport to be denied and no physical non-locality involved.

EPR showed that

QM + Locality<sub>2</sub>  $\rightarrow$  Incompleteness  
(assuming near B)

a QM  $\rightarrow$  Non-locality, or Incompleteness

Yes is the Einstein Dilemma <sup>posed by EPR</sup>

But Bell showed (1964)  $\left\{ \begin{array}{l} \text{EPR leads to the} \\ \text{The EPR paradox} \end{array} \right.$

Completeness  $\rightarrow$  non-locality<sub>3</sub>  
(i.e. near A)

where.

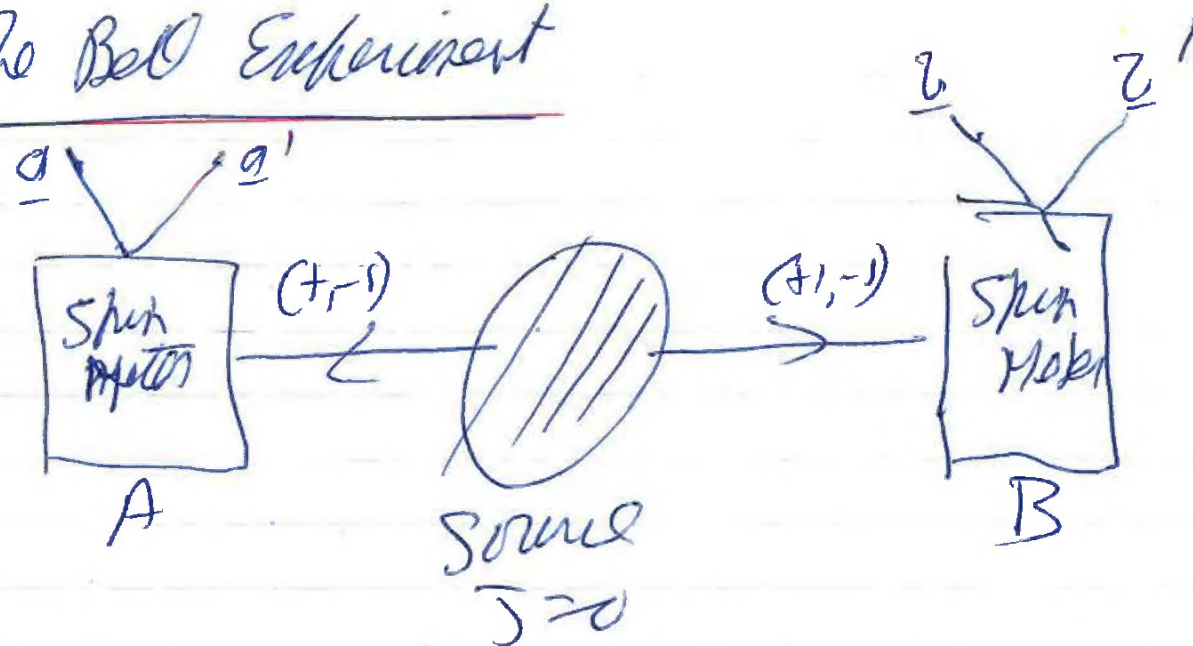
Locality<sub>3</sub> sharp  $\rightarrow$  sharp  
at-a-distance forbidden

The Bell Argument

Locality<sub>3</sub>  $\rightarrow$  Bell Inequality  
which is contradicted by  
QM (and by experiment)

cf a Particular Aspect, Dalibard and  
Roger (P.R.L. (1982))

## The Bell Experiment



$a_n$  denotes spin-component of A-particle parallel to direction  $\underline{a}$  for  $n^{\text{th}}$  pair of particles  
 (similar)  $a_n', b_n, b_n'$

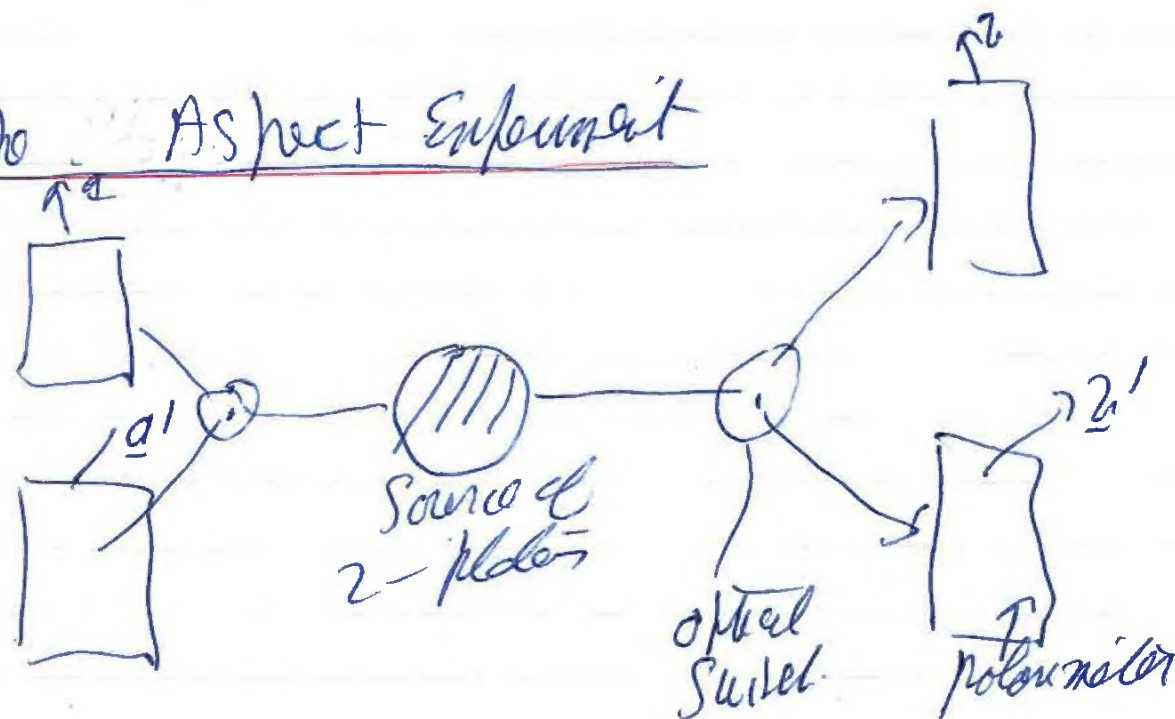
then define correlation coefficients  

$$C(\underline{a}, \underline{b}) = \lim_{N \rightarrow \infty} \frac{1}{N} \sum_n a_n b_n, \text{ etc}$$

The Bell Inequality reads  

$$|C(\underline{a}, \underline{b}) + C(\underline{a}, \underline{b}') + C(\underline{a}', \underline{b}) - C(\underline{a}', \underline{b}')| \leq 2.$$

## The Aspect Experiment



## The Stapp - Eberhard Approach

Can we reformulate argument for Bell Inequality in terms of measurement results so it would apply also to  $\mu$  case B.

Locality<sub>4</sub>: Classical state of macroscopic object,  $\mu$ , is altered at a distance.

## Principle of Local Counterfactual Definiteness (PLCD)

Result of an unperformed experiment has a definite result which does not depend on the setting of a remote piece of apparatus.

(So  $2 \text{ PLCD} \rightarrow 2 \text{ Loc}_4$  for Stapp's ideas)

But in a genuinely indeterministic situation (as in  $\mu$  case B) PLCD is suspect.

Contrast a) clock striking as I hear my hand  
b) pa after delay as I receive my hand.

Even if some experiment in  $\mu$ -case would report same result (counterfactual).

# Statistical Nonlocality

No statistical effects produced at a distance - tagging information at the wrong location - Oxford lecture, notes in Chelsea example.

- Impossibility of the Bell Theorem

Is locality violated in EPR?

Violates	loc <sub>1</sub>	loc <sub>2</sub>	loc <sub>3</sub>	loc <sub>4</sub>	loc <sub>5</sub>
view					
A	no	no	yes	yes	no
B	yes	no	no	no	no
C	no	yes	no	no	no

N.B. Locality problem does not arise in this case as example is ~~apparent~~ since loc<sub>5</sub> not violated.

Query Does Violation of Locality conflict with S.R.?

Violation of loc<sub>3</sub> now remains for loc<sub>1</sub>, cf Shimony (1978) noceful conclusion in case of violation of loc<sub>1</sub>.

Does S.R. prohibit instantaneous effects  
Tachyon theory, Causal loop paradox

# Kochen-Specker Paradox

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So what runs from of non-locality and  
can retain realism. But can we?  
There is another difficulty posed for  
realism by the Kochen-Specker paradox.  
They demonstrated a purely algebraic  
problem about attributing values to  
observables.

Kochen & Specker showed the following.

Given  $A + (A^2 + (FVNC)) \Rightarrow \text{contradiction.}$

[ VR says.  $P_\phi(\lambda) = 0 \Rightarrow \{ \phi \} \neq \lambda. ]$

FVNC says. If  $\hat{A}$  and  $\hat{B}$  are two Hermitian  
and then exists a function  $f$  s.t.  
 $A = f(B)$  then

$$\{A\}^\phi = f(\{B\}^\phi)$$

$$10. \{f(B)\}^\phi = f(\{B\}^\phi)$$

Proof relies on FVNC holding for

$$\hat{A} = f(\hat{B}), \hat{A} = g(\hat{C}) \quad [\hat{B}, \hat{C}] \neq 0.$$

$$\text{So } \{A\}^\phi = f(\{B\}^\phi)$$

$$= g(\{C\}^\phi)$$

— constraint  
on values for  
incompatible magnitudes

N.B. If  $\hat{B}$  &  $\hat{C}$  are measured,  $\hat{A}$  must  
be degenerate for the situation to  
arise.

Insertion  
\*

Extension of notation to two separated systems:

$$[Q \times I]_{\{A, B\}}^{\Phi} (D, E)$$

We can break FUNC and retain realism by supposing that each nat. speaks two languages there then are mappings

Then no designat  $A_B, A_C$

$$\text{Here } [A_B]_{\bar{B}}^{\phi} = f(\{B\})$$
$$[A_C]_{\bar{C}}^{\phi} = g(\{C\})$$

In general we shall assume FUNC\*  
where exp. effective

$$A_B = A_C, \text{ if } \vec{B}, \vec{C} \text{ are commutative}$$

minimal models  
i.e.  $\exists g \text{ s.t. } C = g(B)$   
 $g \in 1:1$

Depend on  $\{B\}$  equivalent class of all  $C$  s.t.  $\exists g \text{ s.t. } C = g(B)$

We can write  $[A]_{\{B\}}^{\phi} = [A_B]_{\bar{B}}^{\phi}$

N.B. FUNC\* is consistent with our independent of VR.

This replicates intentional Contextuality

But the value  $[A]_{\{B\}}^{\phi}$  may also depend on the environment, in particular all affactors not to mention some magnitude  $C$

So we write  $[A]_{\{B\}}^{\phi}(C)$

Then replicates environmental Contextuality

\* incoher

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We now apply these notions to  
two separated systems  
For all  $Q, A, B, C, D, E$ , where  $Q = h(A)$  and  
 $A, B, C, D$  and  $E$  are all monoidal

$$\begin{aligned} \text{OLOC} \\ [Q \otimes I]_{\{A, B\}}^{\phi} (D, E) \\ = [Q \otimes I]_{\{A, C\}}^{\phi} (D, E) \end{aligned}$$

$$\text{ELOE} \\ [Q \otimes I]_{\{A, B\}}^{\phi} (D, E) = [Q \otimes I]_{\{A, B\}}^{\phi} (D, E)$$

where  $\langle A, B \rangle$  is the monoidal physical  
magnitudes  $\phi$  for the first system  
where associated operator  $\hat{O}$  is constructed  
by  $\hat{A} \otimes \hat{B}$  by the relation

$$\hat{O} = \sum_{i,j} c_{ij} \hat{P}_i \otimes \hat{P}_j$$

$$\begin{aligned} \text{where } \hat{A} &= \sum \alpha_i \hat{P}_i & \hat{B} &= \sum \beta_i \hat{P}_i \\ \text{and } c_{ij} &= F(\alpha_i, \beta_j) & \text{where } F: \mathbb{R}^2 &\rightarrow \mathbb{R} \end{aligned}$$

In words-

OLOE locally monoidal physical magnitudes  
on either of two spatially separated  
systems are not split by  
arbitrary contextual relations to  
the specification of different monoidal  
physical magnitudes for the first system

FLOC : the value possessed by a local physical magnitude cannot be changed by altering the arrangement of a remote piece of apparatus which forms part of its measurement context for the concerned system.

VR ① we do not assume LOC in specifying FLOC but FLOC is as only property of local particles of LOC status.

② In terms of measurement results  $LOC \neq FLOC$  but demonstrate a dependence of outcomes recorded by apparatus connected to one system on the setting of the apparatus connected to the other (remote) system.

Redhead - Wesleyan Thesis

We shall show that

\*  $FLOC \neq VR \neq FLOC \neq LOC$

Define Value Rule VR  $\rightarrow P_i^{\phi}(\lambda) = 0 \neq \int \phi^2 \lambda^2$ . (OK-S type)  
Preliminary Comments

Proofs of nonlocality via Bell Inequality have been charged with 'hidden' assumptions. As Fine remarked (1974) 'Hidden variables are not there, hidden assumptions another'.

Fine has claimed (1974) that Bell's  
 original type of proof involved FVNC  
 in the form of the Product Rule (JD  
 assumption that QM joints and phase-space  
 joints were identical)  
 Anyway Fine said we are committed  
 to joint distributions for non-commuting  
 observables even in the Eberhard type  
 of proof (1982) (a h.v. approach this is true)  
 But Fine is mistaken here.  
 Bell  $\rightarrow$  Kohn joints  
 Kohn joints  $\rightarrow$  self joints in a model.  
 But this model need not be the real  
 world!

However all proof of non-locality via  
 Bell's theorem do involve notions  
 of probabilities theory that must be  
 challenged.

Question Can we give a purely algebraic  
 proof of non-locality?

Question posed by Bub (1976) in the form:

Is it possible to extend Maczynski's  
 Theorem (1971) to locally maximal  
 observables?

M's Theorem says we do not need  
 ontological contextualism to allow  
 value assignments to maximal observables

If it's theorem cannot be extended then  
 would mean  
 locally maximal observables must be  
 ontologically contextual  $\Rightarrow$  validation of QM

Unfortunately Demopoulos, Bub, & Humphreys  
have shown that H's theorem -  
can be extended to locally maximal  
theorems.

So OLOC need not be violated

Our next show however that if  
we retain Fine's, VR then  
OLOC & ELOC are both most false.

Violating OLOC means we cannot  
specify a locally maximal observable  
independently of properties relating to  
the whole combined system.  
— leads to alleged holism in which  
it is impossible to make sense of  
a realist account of WH that considers  
properties independently with each of  
two separated systems.

Violating ELOC (if OLOC is assumed)  
is the fact of New Realist Encouraged  
in the Bell-type nonlocal arguments.

The steps in the proof 1 & are as follows:

- 1) Derive EVR from VR and  $\text{Func}^*$   
 EVR of  $\hat{Q}_1$  and  $\hat{Q}_2$  commute and  $\hat{R}$  is  
 maximal operator s.t.  $\hat{Q}_1 = f(\hat{R})$ ,  $\hat{Q}_2 = g(\hat{R})$   
 Then  $P_{\hat{Q}_1, \hat{Q}_2}^\Phi(\lambda, \mu) = 0 \Rightarrow$   

$$[\hat{Q}_1]_{\{\hat{R}\}}^\Phi(R) \neq \lambda$$

$$\vee [\hat{Q}_2]_{\{\hat{R}\}}^\Phi(R) \neq \mu.$$

N.B. EVR for general commuting  $\hat{Q}_1, \hat{Q}_2$   
 is not derivable from VR and  $\text{Func}^*$   
 act.  $\Rightarrow \text{FUNC}$  is contradictory  
 This was proved by Fuchs in 1974.

- 2) As a special case of EVR we  
 obtain:  $\hat{Q} = h(\hat{A})$ ,  $\hat{Q}' = h'(\hat{B})$   
 where  $\hat{A}, \hat{B}$  are maximal  
 $P_{\hat{Q}, \hat{Q}'}^\Phi(\lambda, \mu) = 0$   
 $\Rightarrow [\hat{Q} \otimes \mathbb{I}]_{\{\langle \hat{A}, \hat{B} \rangle\}}^\Phi(A, B) \neq \lambda$   
 $\vee [\mathbb{I} \otimes \hat{Q}']_{\{\langle \hat{A}, \hat{B} \rangle\}}^\Phi(A, B) \neq \mu$

### 3) Incompatibility of EVR and Locality

Consider correlated state of 2 separated  
 systems

$$\bar{\Psi} = \sum C_m |a_m\rangle \otimes |b_m\rangle$$

$\hat{A}$  has eigenvalues  $a_1, \dots, a_N$   
 $\hat{B}$  has eigenvalues  $b_1, \dots, b_N$

Consider nonmaximal operator  $\hat{Q}$  s.t.  
 $\hat{Q} = f(\hat{A}) = g(\hat{A}')$  for maximal  $\hat{A}, \hat{A}'$   
 where  $[\hat{A}, \hat{A}'] \neq 0$ .

Then it is easy to show that

$$[A \otimes I]_{\{\langle A, B \rangle\}}^4 (A, B) = a_m \quad (1)$$

$$\Rightarrow [I \otimes B]_{\{\langle A, B \rangle\}}^4 (A, B) = b_m.$$

$$\text{and } [I \otimes B]_{\{\langle A', B \rangle\}}^4 (A', B) = b_m$$

$$\Rightarrow [f(A \otimes I)]_{\{\langle A', B \rangle\}}^4 (A', B) = f(b_m) \quad (2)$$

Now apply ELOC & OLOC to eqs (1) & (2)

$$[I \otimes B]_{\{\langle A, B \rangle\}}^4 (A, B) = [I \otimes B]_{\{\langle A', B \rangle\}}^4 (A', B)$$

where we obtain FUNC <sup>xx</sup>

$$[f(A \otimes I)]_{\{\langle A', B \rangle\}}^4 (A', B) = f([A \otimes I]_{\{\langle A, B \rangle\}}^4 (A, B))$$

This is not quite FUNC which would have same environmental context on both sides of  $f$ .  
 But can we do best to demonstrate a K-S type contradiction by following this argument parallel to that used by K-S for model state of 2  $2 \times 1$  matrix in their 1967 paper

## Comments

- 1) Fine (1977) and Stairs (1978) claimed CVR was contradictory

But we have derived CVR on a theorem from VR and Fine<sup>x</sup>.

Explanation CVR would be contradictory as we did not allow for violation of locality - this is clear on all levels of Fine and Stairs

- 2) Minimal, transparent use of probability theory - On user A QM is non-local

- 3) What about Stochastic h.v. theories here measurement results are stochastic related to the hidden state of the microsystem (so FM is given up) The Eberhard-type proof now fails because of PLED being inapplicable. VR is not applicable in our approach does not apply

Bell Theorem can be proved if no identity locality = locality.

Perhaps we just have to give up locality - cp Fine.

## Final remark

### Interaction of Physics and Philosophy

- either 1) Physics should be changed in the light of philosophical precepts  
or 2) Philosophical ideas should be modified in the light of new theories in physics.

Role of Philosophy of Physics as I see it is to show what total packages are available — when choice is matter for argument but not decisively settleable.  
(Ideal took on Physics) — slide (c)

The role of philosophy in physics then is to promote understanding of what physics really is committing us to.

Of course theoretical physicists do use philosophical analysis of a sort in their work — Einstein and Bohr are notable examples. However in the case of Einstein general relativity notoriously fails to implement his philosophy, while Bohr gives us a very broken mess — mess of Kierkegaard, Kant and William James, the muddled zone of his former.

But the surprising thing is that muddled philosophy is quite consistent with splendid physics.

In a sense one could claim that Einstein did not understand Relativity

not Bohr quantum mechanics, but  
then one can do physics without  
understanding it - rather like riding  
a bicycle without knowing anything  
about rigid-body dynamics.  
But how much better to do  
physics and understand it - to  
combine the study of physics  
with the study of philosophy of  
physics

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